

40th Turbomachinery Symposium

VIBRATION AND BALANCE ISSUES RESULTING FROM KEYWAY FITTING

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Introduction

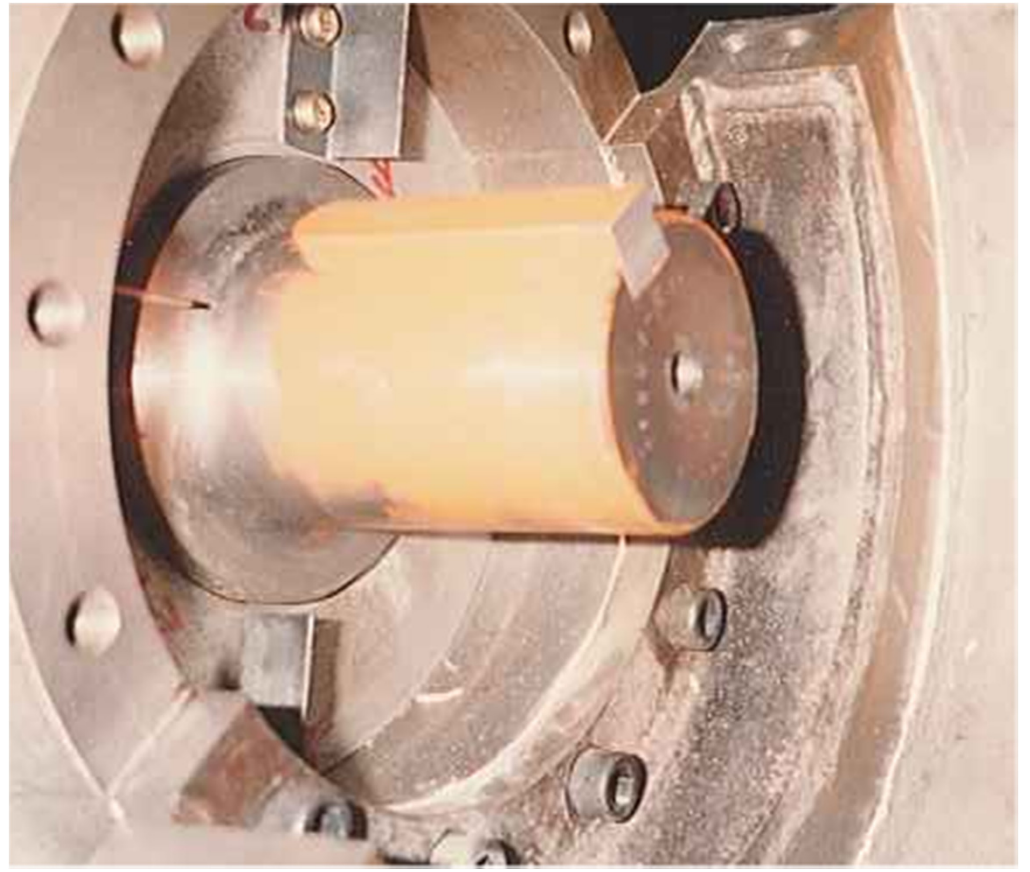
- API 671 4th Edition Paragraph 9.3.5
Requires all machining to be complete prior to balancing, except for the Keyway or Keyways
- Therefore all API 671 coupling must have the Keyway cut after balancing is complete

- Keyway(s) are cut after Balancing, so it is important to replace the material removed from cutting the Keyway properly with the Key
- AGMA 9002-B04 (9112-A04 Metric) provides Recommendations for tolerancing for both Commercial and Precision Class Keys and Keyways
- AGMA 9002-B04 (9112-A04 Metric) also Suggests Keyway fillets radius and Key chamfers

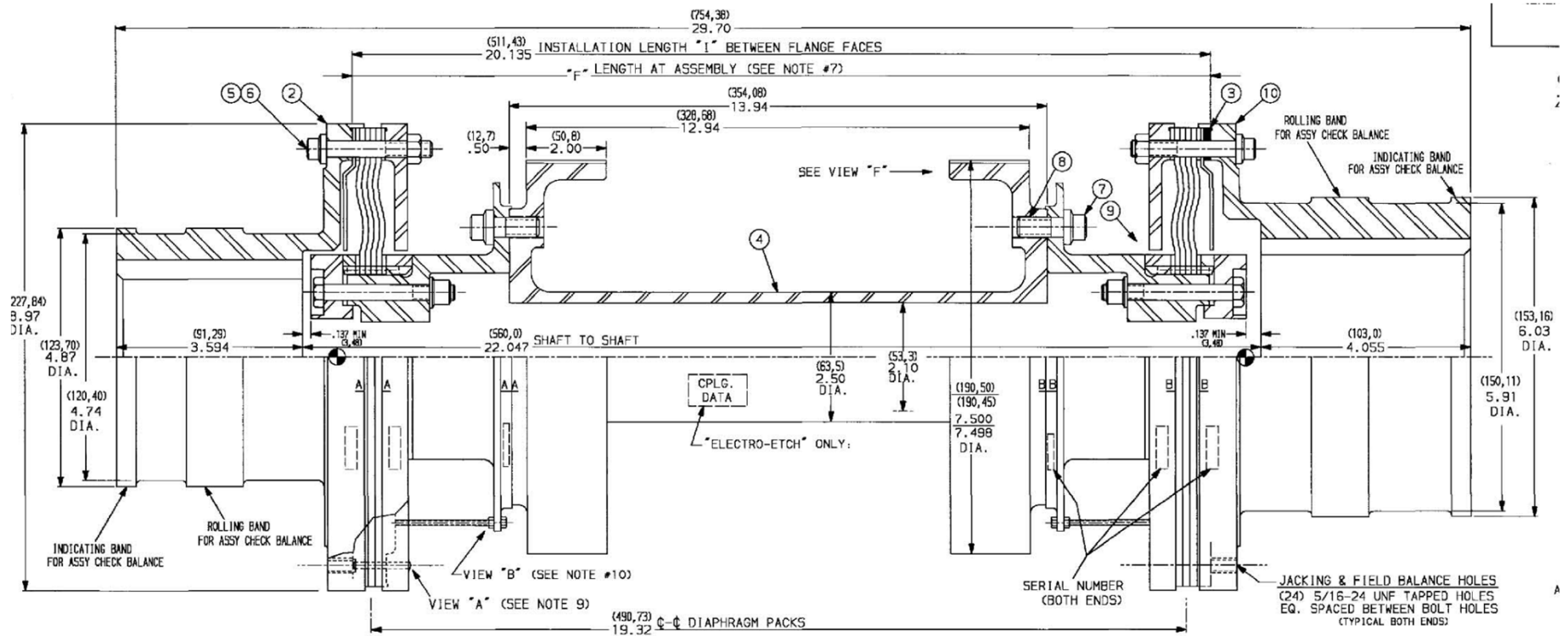
Case

- Application is a Steam Turbine to Gear to Compressor. The Gear to Compressor is Hydraulically fitted and the Steam Turbine and Gear Box Pinion are both Single Keyed.
- The Horsepower is 3300 HP and the Speed Range is 6,370 to 7,495 rpm with a trip speed of 8,657 rpm

Typical Straight Shaft and Key



Coupling Drawing

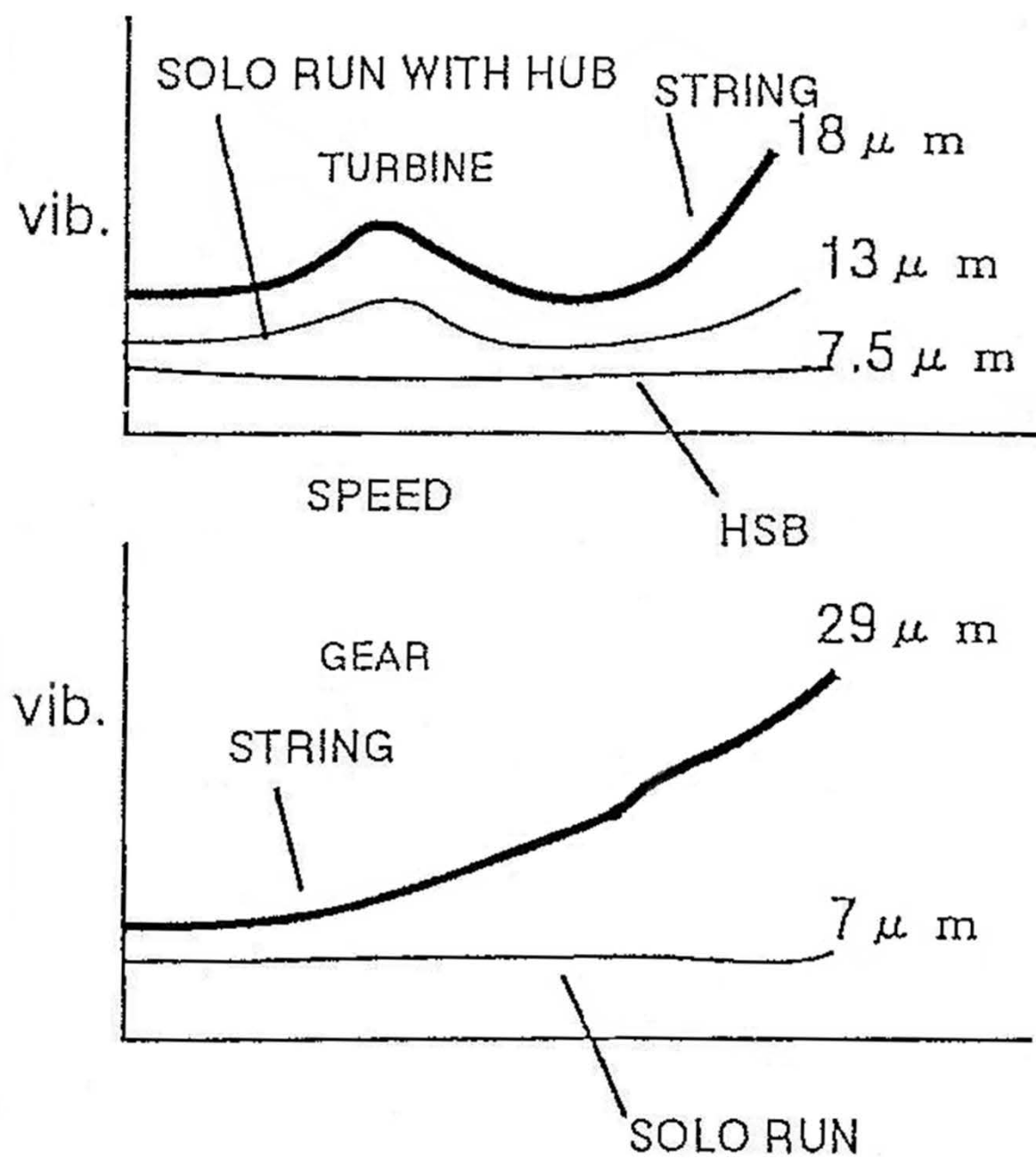


Problem

- When the Gearbox Manufacturer performed a Solo test with the Coupling Hub and Key they found high vibrations and notified us. We asked questions about the key in the hub and never received any answers
- The Gearbox Mfg added field balance weights to complete their test then shipped the equipment on to the Turbine OEM after removing the temporary field weights
- This would have been the best opportunity to address the issue but the Gearbox Mfg assumed that it was a Coupling Balance problem and just passed it on to their customer the Turbine Packager

Turbine OEM

- When the Steam Turbine OEM performed their String test they found high Vibrations at the Turbine (18 μm) and the Gear (29 μm)



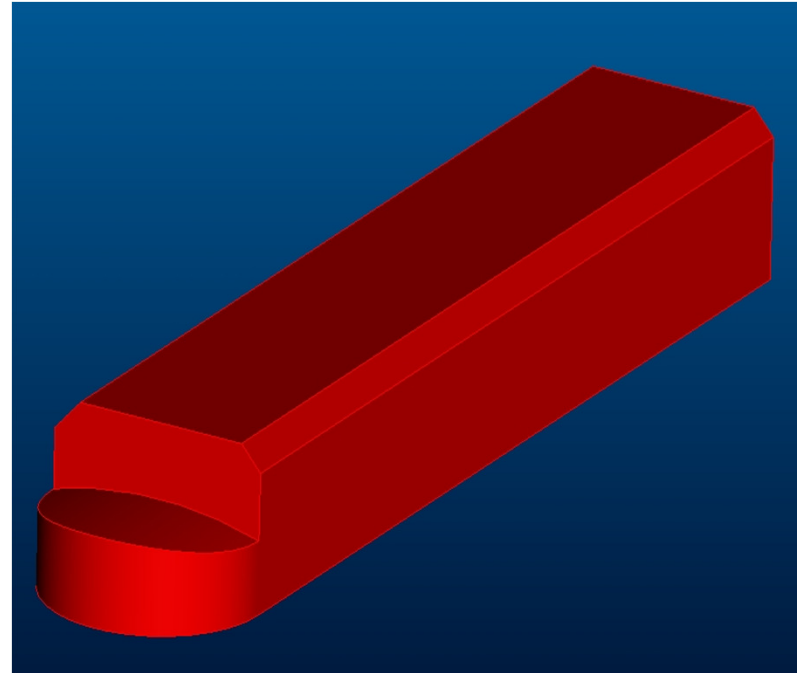
- The OEM believed that the Vibration was from the coupling not being balanced properly. To test this they assembled the Rigid Hubs on mandrels with Dummy keys to verify the Residual Unbalance of the Hubs and found
- Turbine End Hub 408 g-mm (9.8 g-mm allowable)
- Gearbox End Hub 479 g-mm (13.25 g-mm allowable)

- After checking the weight of the Dummy keys it was found that they did not truly represent the mass of the missing material and each was off by approximately 3 grams.
- The correct Dummy key weight was calculated with 3D modeling and weight was added to the existing Dummy keys. This resulted in satisfactory values (within API 671 limits) for the balance of both hubs.

- An Assembly Check Balance was then performed with the correct Dummy Key weight and the Values were also within API 671 Limits

Actual Problem

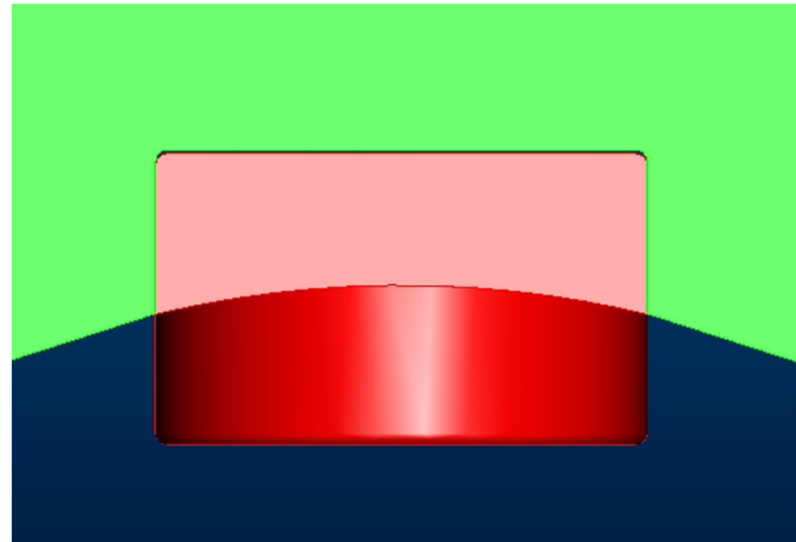
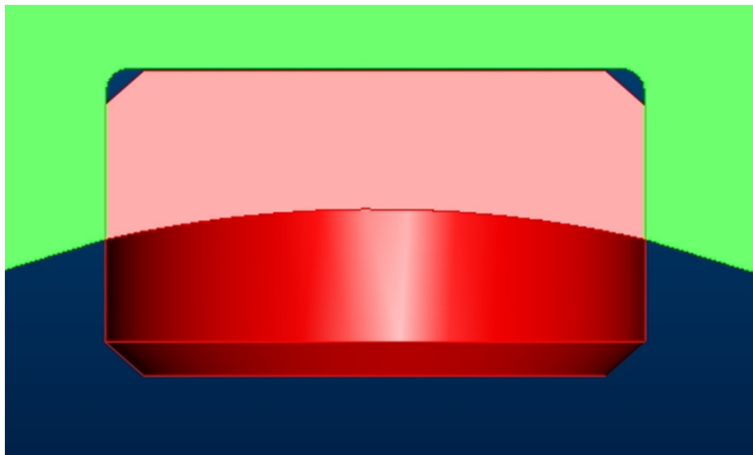
- Since the Gearbox Vibration was the Greatest we looked at the installed Key and found that the Chamfer was very large, AGMA 9112-A04 recommends .60/.80 mm, Actual was 3 mm



- The difference in the weight of the Key with a 0.8 mm chamfer versus a 3 mm was 7 grams or 392 g-mm of Unbalance or more than the total allowable unbalance in the coupling (332 g-mm)
- The installed key had carefully been turned down to the shaft diameter and fitted carefully at the top of the Key, However, the correct size Chamfer was neglected and a chamfer almost 4 times as large was used

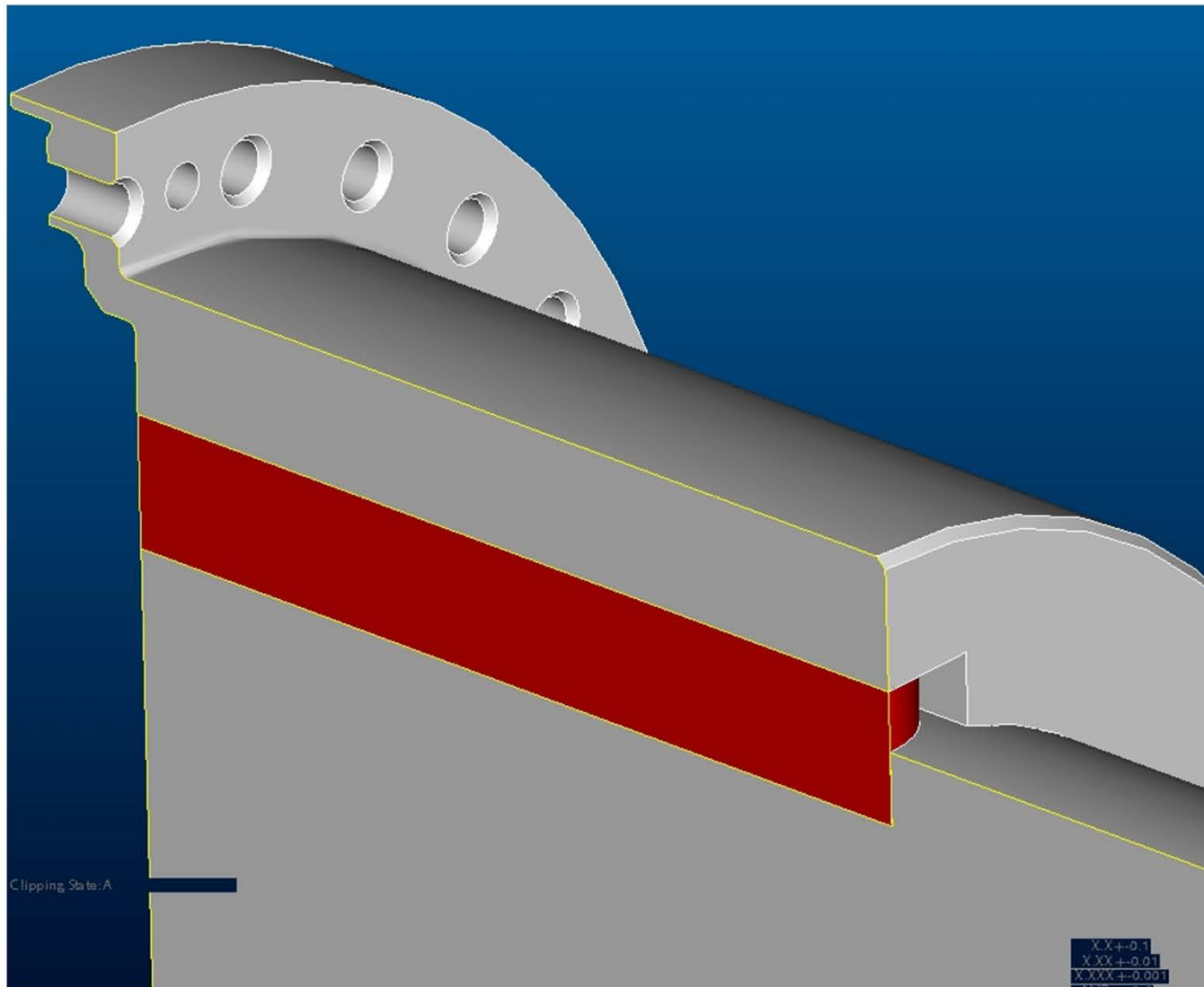
Solution

- A new key was Manufactured with a small Radius to better replace the material that had been removed from cutting the Keyway, Note the new radius matched the AGMA recommended Chamfer .6/.8 mm



- It should be noted that the Turbine shaft Key also had a large Chamfer and was not trimmed down to the shaft and did not extend beyond the Hub, Yet because the Steam Turbine rotor was significantly heavier than the Gear Pinion the lack of filling the Keyway properly had minimal influence on the Vibration

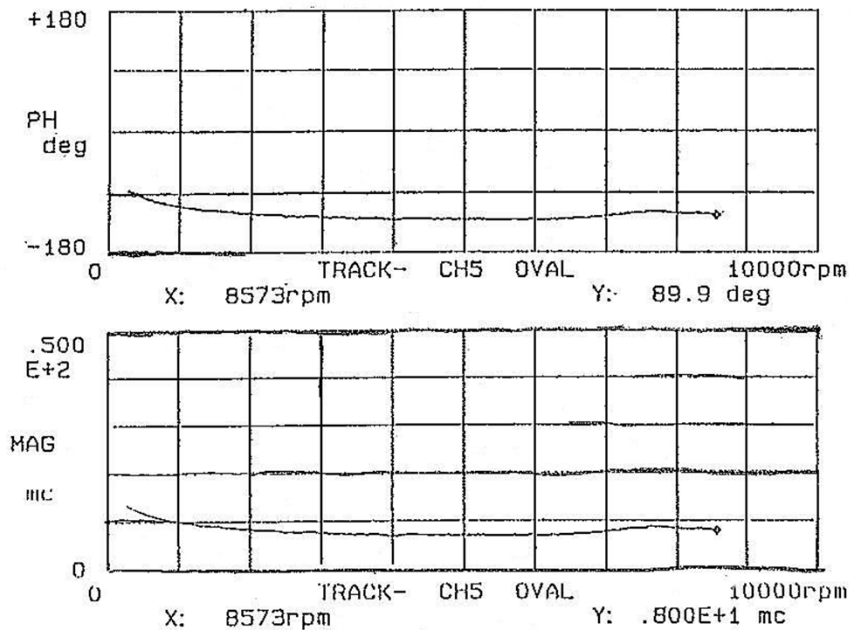
Steam Turbine Key



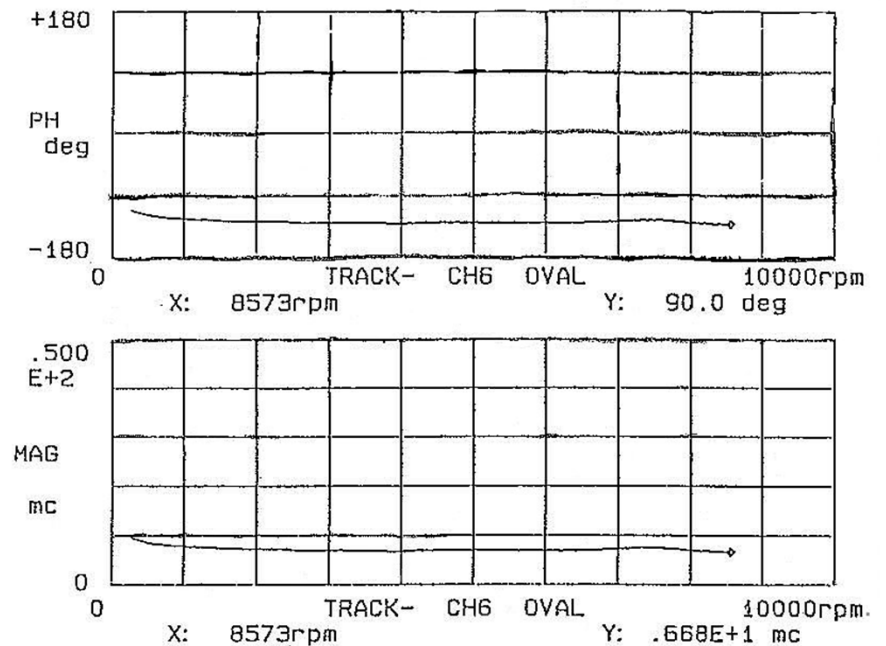
Vibration Results with New Key on Gearbox Only

From the results below you can see that by properly filling the keyway the Vibration level for the train is about the same as the Solo run of the Gearbox

X Vibration Pickup Gearbox
less than 10 μm upto Trip Speed



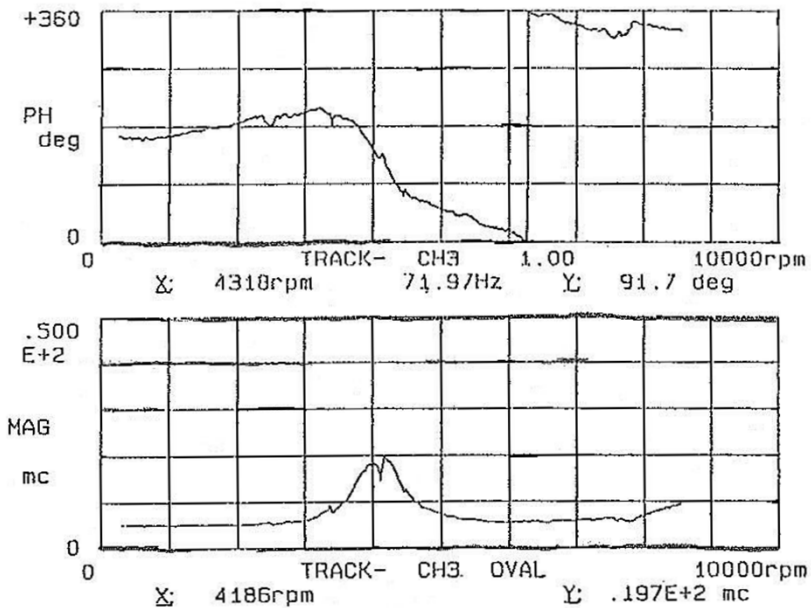
Y Vibration Pickup Gearbox
approximately 7 μm upto Trip Speed



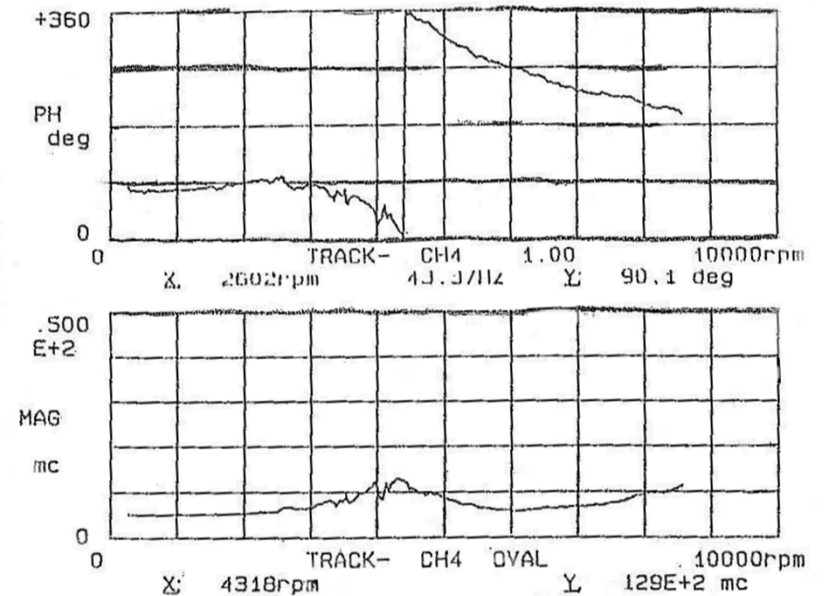
Vibration Results Turbine End

From the results below you can see that by properly filling the keyway on the Gearbox End the Vibration level for the train is about the same as the Solo run of the Turbine, 13 μm

X Vibration Pickup Turbine
matches solo run upto Trip Speed



Y Vibration Pickup Turbine
matches solo run upto Trip Speed



Take Away

- Rotor Analysis can predict the vibration response to unbalance, only if the Amount and Location of the Unbalance are correct
- It is clear that based on the System analysis that the OEM knew the Gear box was sensitive to unbalance and fitted the key around the shaft, and simply used to large a chamfer on the Key
- If the coupling isn't balanced correctly or as in this case the actual Unbalance is greater than used in the Analysis, then you can expect problems

- All you can do is try to minimize the unbalance in the components and try not to add unbalance unnecessarily
- It is important to fit Keys to Keyways per the AGMA or other standard especially on Light Weight High Speed Equipment

- Better yet would be to use a Hydraulic fit for the Shaft so that the unbalance associated with fitting clearances of Keys can be eliminated
- No matter how closely you fit a Key there will always be a clearance and resulting unbalance. This is eliminated with the use of a Hydraulic fit Keyless shaft connection
- As this case shows the difference in a Key Chamfer of 3 mm vs. 0.8 mm can have a significant effect on Vibration